Case Studies

LCA Study of Air Conditioners with an Alternative Refrigerant

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Abstract. In the refrigeration and air conditioning industry, technologies to reduce environmental impacts, such as global warming, ozone-layer depletion, and discharging industrial wastes, are getting much attention nowadays. This paper reports the Life Cycle Assessment conducted to comparatively analyze two air conditioner units for residential use. One is a traditional type with HCFC22 being used for its refrigerant and the other is with HFC410A. Because the main focus of this analysis is on the comparison of the refrigerants, data of the refrigerants used are taken from the actual measurements in their production and disposal stages. As a result, the ozone layer depleting effect can be eliminated completely by using HFC410A. On the other hand, the global warming effect doesn't get reduced extensively by using HFC410A. However, it does so by treating used refrigerants with a proper waste management. Moreover, it can be proved that using HFC410A reduces environmental impacts in all the other impact categories assessed, which are acidification, air pollution, water pollution, and energy consumption. To conclude this case study, replacing HCFC22 with HFC410A for the refrigerant is certainly one of the effective methods for reducing environmental impacts given by air conditioners.

Keywords: Air conditioner; global warming; HCFC22; HFC410A; impact assessment; Japan; ISO 14040; Life Cycle Assessment; ozone layer depletion; refrigerants

Introduction

In 1999, the Kyoto Protocol specified hydrofluorocarbons (HFCs) to be regulated in emission due to their global warming effect, although they have no ozone-layer depleting potential and had been recognized as a promising alternative refrigerant of hydrochlorofluorocarbons (HCFCs) for air conditioners. Therefore, the global warming effect has to be taken into consideration for selecting a refrigerant to replace HCFC. For that reason, an LCA study is conducted to compare HFC and HCFC that are used as refrigerants of air conditioners. Specifically, a new model with HFC410A released for sale this year by Daikin Industries is assessed through its life cycle, and is compared with a traditional model using HCFC22.

Because HFC is one of the substances to be regulated in production due to their global warming effect, recovering and disposing used refrigerants properly at the end of their life cycle is now a demanded task in the industry. For that reason, a combustion process of HFC410A is assumed to be the disposal scenario in this study. Then, two values, 0% and 50%, are set for recovering the ratio of the used refrigerant to estimate the effect of recovery. Recovery means collecting used refrigerant from used products at the site using a collecting device. Usually it takes more than 10 min to pump down the entire refrigerant inside. Since the data quality of the refrigerants is a crucial factor in this study, the data of the refrigerants are taken from the actual measurements in their production stage and disposal stage, and no literature or databases are referred to.

This LCA study is conducted by following the ISO14040 procedure taking 4 phases of Goal and Scope Definition, Inventory Analysis, Impact Assessment, and Interpretation.

1 Discussion

1.1 Goal and scope definition

The purpose of this LCA is to comparatively analyze environmental impact provided by HFC and HCFC used as refrigerants of air conditioners, especially in the views of global warming and ozone layer depletion. For this purpose, two air conditioner units are prepared. One unit is a new model with HFC410A for its refrigerant, and the other is a traditional model with HCFC22. Both of them are the 1998 models of Daikin Industries with the performance of 4kW. The HFC410A model demonstrates an additional technology of energy saving when being used, which overcomes inferior thermodynamic properties of the refrigerant. This energy saving technology includes several factors, including optimization of shapes of the heat exchangers, performance improvement of the compressor, and reduction of heat loss in the system.

For the scope of LCA, a flowchart of the products' life cycle shown in **Fig. 1** is modeled. As shown, LCA will be applied to the entire life cycle of the product that consists of 5 fundamental stages, Material Production, Processing, Transport, Use, and Disposal. And data are accumulated in each of those stages. Also, because recovering used refrigerants from waste products is now a demanded task in the industry, two values are set for the ratio of recovering refrigerant in the Disposal Stage of the HFC410A model – those shown in **Fig. 2** – to analyze the effect of recovery and disposing in combustion process.

Scenario A: 0% of refrigerant is recovered from a waste product.

Scenario B: 50% of refrigerant is recovered, and treated by combustion process.

50% is the target value of recovering that is often discussed for the industry. Also, this combustion process includes incineration of waste refrigerant and neutralization of acid formed during the incineration.

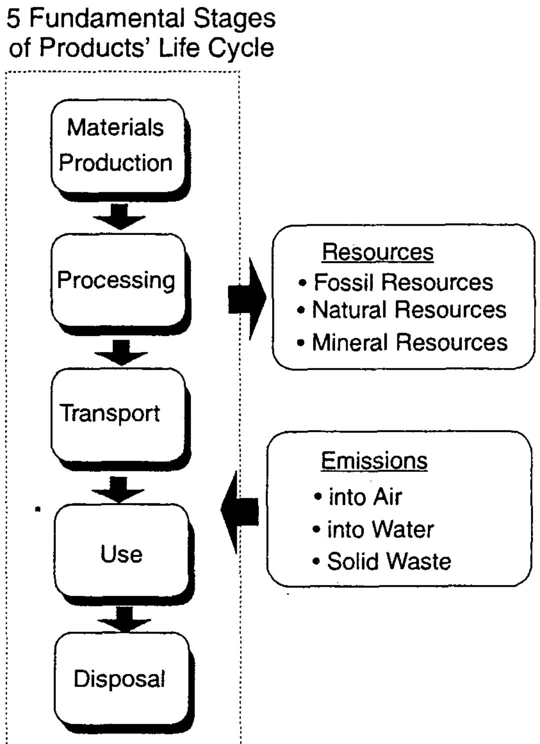

Fig. 1: Products' life cycle model

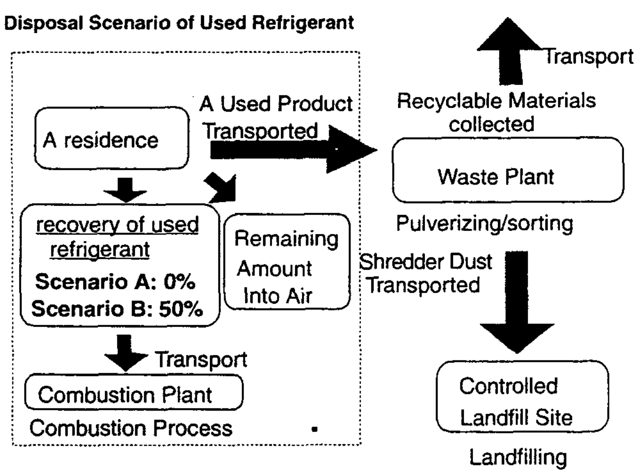

Fig. 2: Disposal model of used products

1.2 Inventory analysis

The data of resources (input) and emissions (output) are accumulated in each of the 5 fundamental stages shown in **Fig. 1**. As for background data, the database mainly referred to is NIRE-LCA ver. 2 of the National Institute for Resources and Environment. The life cycle span of a product is assumed to be 8 years. It is often mentioned that environmental impact is comparatively large during the Use Stage, in particular due to its large electricity consumption. For this reason, assumption of how long the products are used per day is a crucial factor for the assessment. In this case study, it is assumed that the products are used for 8 hours per day for both heating and cooling operation in accordance with the survey result from the ordinary customers. In the Disposal stage, waste metals including iron, copper, and aluminum collected are profitable. These recycled materials are recorded as co-products in the Disposal Stage. In the phase of Inventory Analysis, the qualities of data that are related to the refrigerants are key elements for the precise analysis. And those data are collected from the actual measurements described below as foreground data, and not referred to any databases or literature.

Production of Refrigerants (HCFC22 and HFC410A): The input and output data of refrigerant production are collected from the process in the chemical plant of Daikin Industries.

Disposal of Refrigerants: The input and output data are collected from the experimental combustion process of refrigerants in the pilot plant of Daikin Industries. This process consists of two steps that are incineration of refrigerants, and neutralization of the acids formed during the incineration.

Beside the refrigerants, data for the main component parts of air conditioners, such as compressors, heat exchangers, and electric devices, are collected as foreground data of this case study. As for background data, the database of NIRE-LCA ver. 2 [1] are mainly referred and used for the calculation.

After the data collection overall, CO_2 emission that provides direct impact of global warming is taken as an example of Inventory Analysis. The HCFC22 model and the HFC410A model are comparatively analyzed in terms of CO_2 emission in their life cycles, and shown in **Fig. 3**. The Use Stage takes the largest amount of CO_2 emission in the life cycles of both models.

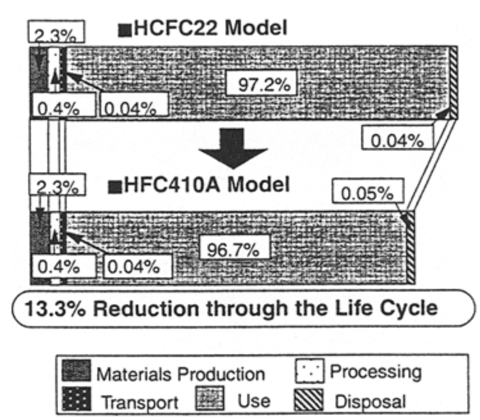

Fig. 3: Comparison of Life Cycle CO_2 emission

Total CO_2 emission by the HFC410A model in its life cycle is 13.3% less than that of the HCFC22 model. This is due to the energy-saving technology of the model when being used, and the refrigerant HFC410A does not demonstrate a direct effect of reducing CO_2 emission by itself. Furthermore,

in order to analyze global warming effect precisely, Impact Assessment has to be conducted taking into account the emissions of the other global warming gases in addition to CO_2.

1.3 Impact assessment

First, global warming effects of the two models are analyzed comparatively for Impact Assessment, that is the primary goal of the study. The global warming effect is expressed in CO_2 equivalents kg using GWP for the analysis. **Fig. 4** shows the comparison result of two models through their life cycles. One of the characteristics these graphs indicate is that the ratio in the Disposal Stage is considerably higher than that of CO_2 emission shown in the graphs in **Fig. 3**. This is because of the effect from used refrigerants emitted into atmosphere. Also, by comparing the HCFC22 model and the HFC410A model with Scenario A in Fig. 4, the GWP value of the HFC410A model in the Use Stage is slightly lower than that of the HCFC22 model, and this is due to the energy-saving technology of the HFC410A model. On the other hand, the GWP value of the HFC410A model in the Disposal Stage is slightly higher than that of the HCFC22 model because it contains more amount of the refrigerant than the HCFC22 model. And the total GWP values of the HFC410A models through its life cycle turn out to be only 1% lower than that of the HCFC22 model. Therefore, next, the HFC410A model with Scenario B is compared to the HCFC22 model. As shown in Fig. 4, the GWP value in the Disposal Stage is remarkably lower than that of the HCFC22 model, and it results with 21% reduction of the GWP value through its life cycle. This result proves that it is successful in reducing the global warming effect to recover the used refrigerant and to dispose it properly.

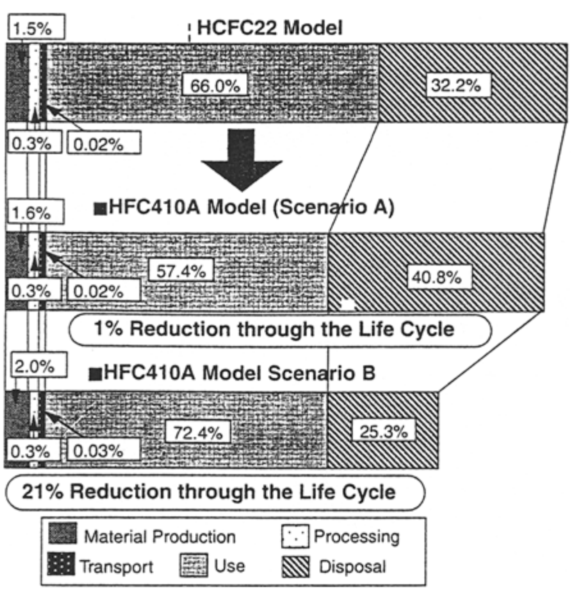

Fig. 4: Comparison of global warming effect

Finally, the two models are comparatively assessed through their life cycles in the other LC impact categories. The impact categories assessed are the ozone layer depleting effect, acidification, air pollution, water pollution, and energy consumption. **Table 1** summarizes their characterization values [2]. The comparison result is shown in the radar chart in Fig. 5. The chart shows the relative ratio of the HFC410A model to the HCFC22 model. From the figure, complete elimination of the ozone layer depleting effect by the HFC410A model is confirmed. Also, the graph shows that the HFC410A model can reduce impact in all of the other categories, that is acidification, air pollution, water pollution, and energy consumption, in the range of 84.8% to 86.7%. This reduction is mostly due to the effect of energy-saving technology of the model. With regard to global warming, the effect given by the HFC410A model is only 1% lower than that of the HCFC22 model if the used refrigerant is not recovered. However, 21% reduction is in prospect if 50% of the used refrigerant is recovered and disposed of properly, as discussed previously.

Table 1: Characterization values of impact categories

Impact Categories	Characterization Values
Global Warming Effect	GWP (CO_2 = 1)
Ozone Layer Depleting effect	ODP (CFC11 = 1)
Acidification	AP (SO_2 = 1)
Air Pollution	Inverse Values of Emission Standards Unit: Nm^3
Water Pollution	Inverse Values of Emission Standards Unit: L
Energy Consumption	Calorific Values of Fuels Unit: MJ/kg

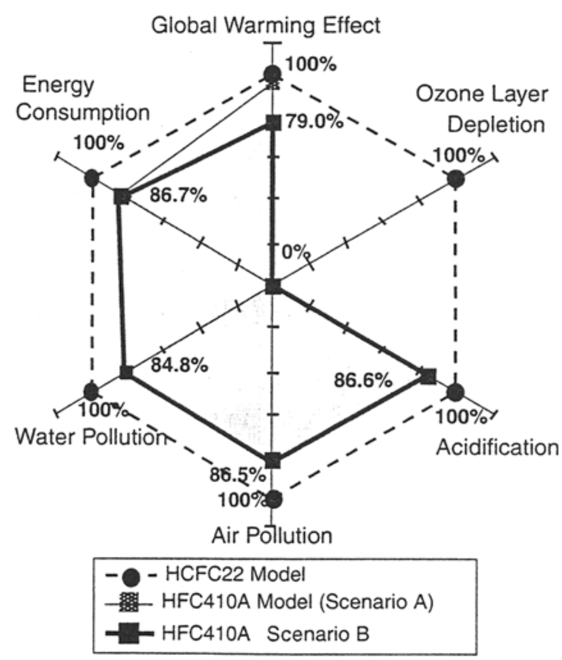

Fig. 5: Comparison of LC impact assessment

1.4 Interpretation

The purpose of this LCA study is to analyze environmental impacts provided by HFC as a refrigerant of air conditioners in comparison with HCFC, especially in view of global warming and ozone layer depletion. As a result of comparing two models, the ozone-layer depleting effect is totally eliminated by using HFC. The global warming effect can be largely reduced if recovery of the used refrigerant is assumed. From these results, the conversion of HCFC22 to HFC410A, which is used as a refrigerant for air conditioners, can possibly become one solution for global environmental protection. In the future, two key subjects can be proposed to use HFC410A in the aspect of the global warming effect. One is to establish an infrastructure that makes it possible to recover a high ratio of the used refrigerant. The other is to decrease the amount of the refrigerant contained inside the products while maintaining a high performance level when being used. In order to maintain high performance, the energy-saving technology is a crucial factor. One technology to achieve energy saving is maximizing the performances of component parts of products, consisting of heat exchangers, compressors, fans, and control systems. Another technology is system designing to increase the total system performance and to reduce heat loss in the system.

2 Future Schemes

Two future schemes of LCA are proposed and discussed in this section. One is reliability of LCA data, and the other is LCA methodology that corresponds to social and governmental strategies to protect the environment.

First, LCA is now in progress of being developed as a product-design tool in Daikin Industries, LTD. For the development of the tool, reliability of the LCA data is a decisive factor for the tool's quality. For that reason, LCA data that are based on actual measurements in manufacturing processes need be collected for the tool. However, one problem raised is the difficulty of data collection of household appliances such as air conditioners, because they are composed of numerous component parts purchased from outside. Therefore, getting cooperative actions from the suppliers of those component parts is essential in order to establish a complete database of the products.

The second scheme is regarding LCA methodology that is able to valuate environmental impacts that correspond to the social problems. Because each industrial product owns individual environmental problems socially, LCA should ideally be applied to each industrial product in a different approach that corresponds to the particular problems. For example, environmental problems related to air conditioners are: (1) emission of global warming gas, (2) ozone layer depletion by the refrigerants, and (3) increase in industrial wastes. The government is now proceeding to legislate for environmental impact reduction on all of those three subjects. It is possible to apply LCA to (1) and (2) with current LCA methodologies, however, methodologies that can valuate (3) are still under development. Currently, researches of LCA methodology that can valuate 'Land Use' as an impact category are in progress, and the authors are paying attention to the progress. In the future, those three categories are possibly considered to be the three principal categories for valuating air conditioners. Moreover, it is convenient for product designers if those three categories can be unified and expressed as a single index point.

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